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(54) Reflective liquid crystal device

(57) A reflective liquid crystal device comprises a polarising beam splitter 30 and a mirror 2 between which are disposed retarders 31, 32, 33. At least one of the retarders 32 is a liquid crystal element whose retardation is variable, or whose optic axis is switchable. In a DARK state of the device the retarders combine to rotate the plane of polarisation of light directed by the polarising beam splitter 30 towards a reflector 2 by n x 180°, where n is an integer. The light returned to the polarising beam splitter is therefore directed back towards the light source. In a BRIGHT state of the device, the retarder arrangement rotates the plane of polarisation of light directed by the polarising beam splitter 30 by 90° , and this light is transmitted by the polarising beam splitter.

FIG 1(a)

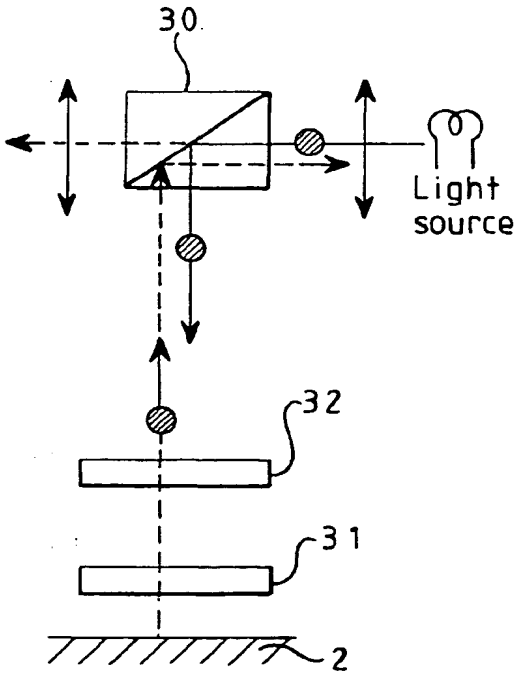

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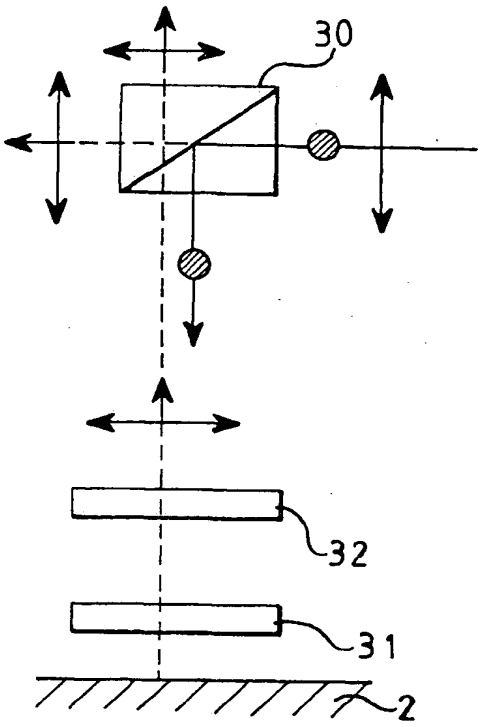
FIG 1(b)



D scription

[0001] The present invention relates to a reflective liquid crystal device utilising a polarising beam splitter. Such devices may be used, for instance, in liquid crystal projection displays.

[0002] Proc. Ind. Acad. Sci., 1955, 41A 130 and 137 disclose circular polarisers and quarter waveplates made of combinations of birefringent plates to provide improved achromaticity. The individual retarders are combined with different azimuthal orientations of their optic axes to achieve the improvement in achromatic performance.

[0003] Seki et al, Mol. Cryst. Liq. Cryst., 1995, 263, 499 and Seki et al, Eurodisplay, 1996, 464 disclose a liquid crystal device (LCD) of the reflective electrically controlled birefringence (ECB) type comprising a nematic liquid crystal and a quarter waveplate. The optic axis of the quarter waveplate is crossed with that of the nematic liquid crystal and is at 45° to a polariser disposed on one side of the nematic liquid crystal. The untwisted liquid crystal and quarter waveplate are disposed between the polariser and a mirror and a normally white state is achieved with the liquid crystal providing a retardation of $\lambda/4$. A black state is achieved by controlling the liquid crystal so as to provide zero retardation. This black state is effectively provided by the quarter waveplate and is achromatic only to the degree that the quarter waveplate is achromatic. A further retarder of negative birefringence with its optic axis perpendicular to its plane may be included to improve viewing angle performance.

[0004] Uchida et al, Asia Display, 1995, 599 discloses a reflective display in which a polariser and a mirror are disposed on opposite sides of a Hybrid Aligned Nematic Liquid Crystal Layer and a Retarder. The retarder is biaxial having an optic axis out of the plane to improve viewing angle and an in-plane optic axis which co-operates with the retardation of the liquid crystal layer to provide black and white states. The retarder in-plane axis is at 45° to the polarising axis of the polariser and is crossed with the optic axis of the liquid crystal layer. A normally black state is provided when the net retardation of the liquid crystal layer and the retarder is equal to $\lambda/4$. A white state is provided when the retardation of the liquid crystal is such that it cancels the retardation of the retarder. Such a display depends for its achromaticity on optimising the dispersion of the optical elements.

[0005] Ishinabe et al, Eurodisplay, 1996, 199 discloses a full colour reflective LCD in which a HAN liquid crystal layer and a biaxial retarder are disposed between a linear polariser and a mirror. The optic axis of the HAN layer is crossed with the optic axis of the retarder and is at 45° to the polarising axis of the polariser. A normally black state is achieved by making the differenc between retardations of the liquid crystal layer and the retarder equal to $\lambda/4$. Achomaticity is improved by adjusting the dispersion of materials of th liquid crystal layer and the retard r so that the bir fiingences partially compensate ach other.

[0006] Kuo et al, Asia Display, 1995, 135 also discloses an LCD in which a HAN liquid crystal layer and a biaxial retarder are disposed between a linear polariser and a mirror. A dark state is provided when the total retardation is equal to an odd number of quarter wavelengths. The retarder has an in-plane optic axis which is crossed with the liquid crystal axis and is at 45° to the polariser axis. The display may be operated in the normally black mode, as described hereinbefore, or in the normally white mode, in which case a larger passive retarder is used. Achromaticity may be improved by optimising the dispersion of the elements or by adjusting the dispersion so that the birefringences compensate each other.

[0007] Wu et al, Applied Physics Letters, 1996, 68, 1455 discloses a reflective LCD in which a twisted nematic liquid crystal cell and a retarder are disposed between a polariser and a mirror. The twisted nematic liquid crystal cell has a twist angle of 90°, is relatively thin, and has its input director angled at 20° to the axis of the polariser. The retarder provides a retardation of $\lambda/4$ and has an optic axis angled at 45° to the polariser axis. The cell operates in the normally white mode where the retardations of the liquid crystal cell and th retarder cancel each other in the white state and the black state is obtained by reducing the retardation of the liquid crystal cell to zero. Accordingly, the achromaticity depends on the achromaticity of the retarder.

[0008] Kuo et al, Eurodisplay, 1996, 387 discloses a similar twisted nematic display which is operated in the normally white mode and again achieves a black state whose achromaticity depends on the achromaticity of the retarder.

[0009] Fukuda et al disclose in three papers (IDRC, 1994, 201; SID Journal, 1995, 3, 83; Asia Display 1995, 881) a reflective supertwisted nematic (STN) LCD comprising a single polariser and a single retardation film. The twist of the liquid crystal is between 220 and 260° and the device operates in the normally white mode. STN liquid crystal is used to allow high multiplex ratios i.e: small voltage differences between on and off voltages and hence a large value of $d\Delta n$ of the liquid crystal, for instance greater than 0.6 micrometres. Achromaticity is improved by varying the dispersive properties of the liquid crystal and the retarder.

[0010] EP-A-0 389 240, on which the preamble of claim 1 is based, discloses a projection system that uses a polarising beam splitter. Light incident on the polarising beam splitter is directed towards a reflective liquid crystal device. A $\lambda/4$ retarder is disposed between the polarising beam splitt r and the reflectiv liquid crystal devic .

[0011] EP-A-0 389 240 also discloses a full colour projection system, in which white light is split into red, green and blue components. Thre polarising beam splitters are provided, one each for r ceiving red, green and blue

light. Light incident on each of the polarising beam splitters is directed to a respective reflective liquid crystal device via a λ/4 retarder.

[0012] A first aspect of the present invention provides a reflective liquid crystal device comprising: a polarising beam splitter, a polarisation preserving reflector, and a retarder arrangement comprising at least two retarders, a first of which is disposed between the beam splitter and the reflector, and a second of which is disposed between the first retarder and the reflector, at least one of the first and second retarders comprising a liquid crystal layer which is switchable between a dark device state, in which the retarder arrangement rotates the plane of polarisation of plane-polarised light directed by the beam splitter towards the reflector by substantially n x 180°, where n is an integer, and a bright device state; characterised in that in the bright device state the first retarder has a retardation of substantially λ/2 and the second retarder has a retardation of substantially λ/4.

[0013] Disposing the substantially λ/4 retarder between the substantially λ/2 retarder and the reflector provides improved performance compared with the devices of EP-A-0 389 240.

[0014] By placing the substantially λ/4 retarder between the substantially λ/2 retarder and the reflector, two advantages over EP-A-0 389 240 are obtained.

[0015] Firstly, the bright state of the devices of this invention is less wavelength-dependent than the devices of EP-A-0 389 240. This leads to a more efficient device.

[0016] Secondly, in the case in which the substantially λ/2 retarder comprises an in-plane switching liquid crystal material (such as an antiferroelectric liquid crystal or a similar liquid crystal), in this invention the liquid crystal material has to switch only by ± 22.5° to obtain the bright state. In contrast, if such an in-plane switching liquid crystal material were used for the substantially λ/2 retarder, with a substantially λ/4 retarder disposed between the substantially λ/2 retarder and the polarising beam splitter as in EP-A-0 389 240, then the in-plane switching liquid crystal would have to switch by ± 45° to obtain the maximum bright state. Many known in-plane switching smectic liquid crystal materials (for example, antiferroelectric liquid crystals or similar liquid crystal materials) exist which can switch to ± 22.5°, but there are few known materials which can switch to ± 45°. In the present invention, therefore, it is straightforward to find a liquid crystal material that will switch sufficiently to obtain the maximum bright state, and this again leads to a device that is more efficient device than those disclosed in EP-A-0 389 240.

[0017] The retarder arrangement may rotate the plane of polarisation of plane-polarised light directed by the beam splitter towards the reflector by substantially 90° in the bright device state.

[0018] In the bright device state the first retarder may have its optic axis at an angle α to the plane of polarisation of the plane polarised light directed by the beam splitter towards the reflector, and the second retarder may have its optic axis at an angle 2α + 45° to the plane of polarisation of the plane polarised light directed by the beam splitter towards the reflector.

[0019] The angle α may be substantially equal to 22.5°.

[0020] Alternatively, the first and second retarders may each comprise a liquid crystal layer, and a may be substantially equal to 15°.

[0021] The first retarder may comprise the liquid crystal layer whose optic axis rotates by an angle substantially equal to 22.5° about the normal direction of light passage during switching.

[0022] The first retarder may comprises the liquid crystal layer and have a retardation which is switchable between substantially pλ/2 and substantially (p+1)λ/2, where p is an integer.

[0023] The integer p may be equal to zero or one.

[0024] The liquid crystal layer may be an out-of-plane switching nematic liquid crystal.

[0025] The liquid crystal layer may be a ferroelectric liquid crystal.

[0026] The liquid crystal layer may alternatively be an antiferroelectric liquid crystal.

[0027] The liquid crystal layer may alternatively be an electroclinic liquid crystal.

[0028] The liquid crystal layer may alternatively be an in-plane switching nematic liquid crystal.

[0029] The device may further comprise a second polarisation preserving reflector, and another retarder arrangement comprising a third retarder disposed between the beam splitter and the second reflector and a fourth retarder disposed between the third retarder and the reflector, at least one of the third and fourth retarders comprising another liquid crystal layer which is switchable between a dark device state, in which the another retarder arrangement rotates the plane of polarisation of plane-polarised light directed by the beam splitter towards the another reflector by substantially n x 180°, where n is an integer, and a bright device state.

[0030] A second aspect of the invention provides a reflective liquid crystal device comprising: a polarising beam splitter for directing light towards a wavelength separator; first and second polarisation preserving reflectors, the wavelength separator directing light of a first wavelength towards the first reflector and directing light of a second wavelength different from the first wavelength towards the second reflector; a first retarder arrangement disposed in the optical path between the beam splitter and the first reflector; and a second retarder arrangement disposed in the optical path between the beam splitter and the second reflector;

wherein the first retarder arrangement is switchable between a dark state, in which the first retarder arrangement rotates the plane of polarisation of plane-polarised light of the first wavelength directed by the beam splitter towards the first reflector via the wavelength separator by substantially n x 180°, where n is an integer and a bright state;

and wher in th s cond retarder arrangement is switchable b tween a dark state, in which the second retarder arrangement rotates the plane of polarisation of plan -polarised light of th second wav length directed by the beam splitter towards the second reflector via the wavelength separator by substantially n x 180°, where n is an integer and a bright state;

characterised in that the first retarder arrangement comprises, in the bright state, a first retarder having a retardation of substantially λ/2 disposed between the beam splitter and the first reflector and a second retarder having a retardation of substantially λ/4 disposed between the first retarder and the first reflector;

and in that the second retarder arrangement comprises, in the bright state, a third retarder having a retardation of substantially λ/2 disposed between the beam splitter and the second reflector and a fourth retarder having a retardation of substantially λ/4 disposed between the third retarder and the second reflector.

[0031] The first retarder may comprise a first liquid crystal layer; and the third retarder may comprise a second liquid crystal layer.

[0032] The first liquid crystal layer may be the second liquid crystal layer.

[0033] It is thus possible to provide an LCD which is suitable for use in reflective displays. High brightness and contrast are achieved in a reflective single polariser device which has a wide acceptance angle and a fast response speed. It is further possible to achieve a bright state having a degree of achromaticity which is substantially improved compared with known displays of the single polariser and reflector type. The optic axes of the retarders are oriented such that the combinations gives a retardation of λ/4 for the input polarised light from the polariser over a wide range of wavelengths in the bright state. The bright state is therefore very bright and achromatic and this in turn gives high contrast when combined with the dark state. The retarders need not be made of the same material and the dispersive properties of the retarder materials are not substantially important for achieving achromaticity, although the best display is obtained by using identical materials of as low dispersion as possible.

[0034] Thus, a high brightness device is provided because of the use of a single polarising beam splitter. Good achromatic behaviour permits high contrast to be achieved. The use of optically thin layers permits a wide acceptance angle.

[0035] The present invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1(a) is a diagrammatic view of a display constituting a first embodiment of the invention in its DARK stat ;

Figure 1(b) is a diagrammatic view of a display constituting the first embodiment of the invention in its BRIGHT state;

Figure 2(a) is a schematic view illustrating optical paths for a comparative display device as describ d in co-pending UK patent application No 9622733.5;

Figure 2(b) is a schematic view illustrating the optical paths for a display device according to the invention;

Figure 3 illustrates the polarisation states for the operation of a display according to the first embodiment of the invention in a BRIGHT state;

Figure 4 is a diagrammatic view of a display constituting a second embodiment of the invention;

Figure 5 shows a theoretical calculation of the reflectivity, in the BRIGHT state, of a display device according to the first or second embodiment of the invention;

Figure 6 is a diagrammatic view of a display according to a third embodiment of the invention;

Figure 7 is a diagrammatic view of a display according to a fourth embodiment of the invention;

Figure 8 is a diagrammatic view of a display according to a fifth embodiment of the invention;

Figure 9 is a diagrammatic view of a display according to a sixth embodiment of the invention; and

Figure 10 is a diagrammatic view of a display according to a seventh embodiment of the invention.

[0036] Figures 1(a), 1(b) and 2(b) are schematic views illustrating an embodiment of this invention. This has some similarities to the devices described in co-pending UK patent application No: 9622733.5, but it uses a polarising beam splitter in place of a linear polariser.

[0037] The symbols TM and TE denote two orthogonal states of plane polarised light. In the TM state the light is polarised with the electric field vector in the plane of the paper, and in the TE state the light is polarised with the electric field vector perpendicular to the plane of the paper. The polarising beam splitter 30 is illuminated with light which contains both TM and TE components. The TE component is directed by the beam splitter 30 towards a polarisation preserving reflector 2, whereas the TM component passes through the beam splitter 30, and is lost in this embodiment.

[0038] Optical components 31, 32 are provided in the optical path between the beam splitter 30 and the reflector 2. If these are chosen such that the light reflected back towards the beam splitter 30 is still in the TE polarised state, the light will be directed back along the

path of the incident light (Fig 1(a)). If, however, the optical components in the optical path between the beam splitter 30 and the reflector 2 are such that the reflected light incident on the beam splitter 30 is now in the TM polarisation state, the reflected light will not be directed back towards the light source but will pass through the beam splitter 30 (Fig 1(b)).

[0039] In a direct view reflective display such as those described in UK 9622733.5, it is usual to consider only paths of INCIDENT light and REFLECTED light. In order to describe embodiments of this invention, however, it is necessary also to consider the path of IMAGING light. In a direct view reflective display the INCIDENT, IMAGING and REFLECTED paths are collinear (Fig 2(a)). This is not the case for a device based on a polarising beam splitter, however - only the INCIDENT and REFLECTED paths are collinear (Fig 2(b)). Moreover if the REFLECTED path is bright then the IMAGING path is dark, and vice-versa.

[0040] In the embodiment shown in Figures 1(a) and 1(b), the component denoted by 31 is a $\lambda/4$ retarder with its optic axis at $45 + 2\alpha°$ to the plane of polarisation of the light directed towards the reflector 2 by the beam splitter 30 (that is, at $45 + 2\alpha°$ to the plane of polarisation of the TE component).

[0041] Reference numeral 32 denotes a nematic liquid crystal cell. In the BRIGHT state, shown in Figure 1 (b), the liquid crystal cell is a $\lambda/2$ retarder with its optic axis at $\alpha°$ to the plane of polarisation of the TE light.

[0042] The operation of the device in this state is shown in Figure 3. Linear polarisations are indicated by "L", left handed circular polarisation is indicated by "C_L" and right handed circular polarisation is indicated by "C_R".

[0043] The beam splitter 30 is represented in Figure 3 as a linear polariser, for convenience. Unpolarised light is incident on the beam splitter 30 from a light source (not shown in Figure 3), and the beam splitter 30 directs plane polarised TE light towards the liquid crystal cell 32. In the BRIGHT state the liquid crystal cell 32 is a $\lambda/2$ retarder, and it will rotate the plane of polarisation of the TE light by $2\alpha°$.

[0044] When the light is incident on the $\lambda/4$ plate 31 its plane of polarisation is at 45° to the optic axis of the $\lambda/4$ plate 31. The light is thus converted to circularly polarised light by the $\lambda/4$ plate 31.

[0045] Upon reflection by the reflector 2, the light is converted to circularly polarised light of the opposite hand. The $\lambda/4$ plate 31 will therefore convert it to plane polarised light with the plane of polarisation at $-2\alpha°$ to the plane of polarisation of the TE light, and this will be rotated to $4\alpha°$ by the liquid crystal cell 32. Light returned to the beam splitter 30 can therefore be regarded as a combination of the TE and TM polarisation states, and the TM component will pass through the beam splitter 30 along the imaging path.

[0046] To obtain the DARK state of the device, the liquid crystal cell is switched to provide zero retardation, so that the polarisation of the TE light is not changed by either retarder 31, 32 if $\alpha = 22.5°$. The light returns to the beam splitter 30 still in the TE state, and is directed along the REFLECTED path.

[0047] A high voltage is usually required to put a planar aligned nematic liquid crystal into a state in which it provides zero retardation. In an alternative embodiment of the invention shown in Figure 4, therefore, an additional retarder 33 is provided in the optical path between the beam splitter 30 and the reflector 2. This additional retarder 33 has its optic axis crossed with the rubbing direction of the nematic liquid crystal. The combination of the additional retarder 33 and the liquid crystal panel 32 provide zero retardation at a lower applied voltage across the liquid crystal panel 32. Although the additional retarder 33 is shown between the liquid crystal panel 32 and the $\lambda/4$ plate 31 in Figure 4, it is possible to interchange the positions of the additional retarder 33 and the liquid crystal panel 32.

[0048] An alternative to providing the additional retarder 33 is to use a biaxial $\lambda/4$ retarder for the $\lambda/4$ retarder 31. Alternatively, a negative $\Delta\varepsilon$ homeotropically aligned nematic liquid crystal panel can be used.

[0049] Preferably, α is 22.5° if the component 31 is a fixed retarder and the component 32 is a switchable liquid crystal cell. If components 31 and 32 are both switchable liquid crystal cells, then preferably $\alpha = 15°$ in the BRIGHT state . The light returned to the beam splitter 30 contains only the TM component in this case, so all light returned to the beam splitter 30 will pass along the IMAGING path (ignoring absorption losses in the beam splitter 30).

[0050] In an alternative embodiment of the invention, the liquid crystal panel 32 is a $\lambda/2$ retarder with an optic axis whose direction can be switched between 0° to the plane of polarisation of the incoming TE light and ±22.5° to the plane of polarisation of the TE light.

[0051] In the BRIGHT state of the device, the optic axis of the liquid crystal panel 32 is switched to ±22.5° to the plane of polarisation of the TE light. The liquid crystal panel 32 and the $\lambda/4$ retarder 31 combine to rotate the plane of polarisation of the incident light by 90°, as described above for the embodiment of Figures 1(a) and 1(b), so the light returned to the beam splitter 30 passes through the beam splitter 30 along the imaging path.

[0052] To obtain the DARK state of the device, the optic axis of the liquid crystal panel 32 is switched to 0° to the plane of polarisation of the TE light. The polarisation of the light is unaffected by either the liquid crystal panel 32 or the $\lambda/4$ retarder 31, and the light returns to the beam splitter 30 in the TE polarisation state and is directed along the REFLECTED path.

[0053] In this embodiment, the liquid crystal panel 32 can contain a ferroelectric liquid crystal (FLC), a distorted helix ferroelectric liquid crystal (DHF), a short-pitch bistable ferroelectric liquid crystal (SBF), an antiferroelectric liquid crystal (AFLC), or an in-plane switching

nematic liquid crystal (IPSN). Th pref rred liquid crystal is a antiferro lectric liquid crystal (SBF or DHF). Using this, th liquid crystal panel would have its optic axis at 0° to the plan of polarisation of the TE light when no voltage is applied to the liquid crystal panel, and applying a voltage would switch the optic axis to ±22.5°. Thus, the device would be a "normally black" device (that is, in the DARK state when no voltage is applied).

[0054] Figure 5 is a theoretical calculation (assuming perfect polarisation) of the reflectivity in the BRIGHT state as a function of wavelength for the devices of Figures 1(a), 1(b) or 4 as a full line. The broken line shows the transmissivity obtained using a single birefringent element of λ/4 retardation having its optic axis at 45° to the polariser direction (ZL1-2293 material). The reflectivity of the devices of the present invention is more achromatic and, as a result, the device has a higher overall brightness. Values for the CIE x/y co-ordinates and luminance are shown below.

	x	y	L
Single LC panel, λ/4	0.3144	0.3474	96.8%
This invention	0.3137	0.3346	99.3%
White point, D65	0.3127	0.3290	100%

[0055] A full colour display can be obtained by providing colour filters in the liquid crystal panel, or by using a time-multiplex method.

[0056] Figure 6 shows a two panel system, in which a second liquid crystal panel 32', a second λ/4 retarder 31' and a second reflector 2' are provided in the path of the TM polarised component of light incident on the beam splitter. If the second liquid crystal panel 32' and the second λ/4 retarder 31' combine to change the polarisation of the light returned to the beam splitter by the second reflector from TM to TE, then the light returned to the beam splitter by the second reflector is directed along the IMAGING path by the beam splitter as shown in Figure 6.

[0057] If different information is shown on the two liquid crystal panels, the system can be used to provide a 3-D projection system. Alternatively, the system can be arranged to divide the grey level load between the two panels. If the two panels display the same information, then the brightness of the display is increased.

[0058] Figure 7 shows a three panel system, in which the beam splitter directs the TE polarised component of the incoming light towards a wavelength separator 34, such as a dichroic prism, which directs red, green and blue light in three mutually different directions. Three reflectors 2B, 2G, 2R are provided for blue, green and red light respectively. Three sets of a liquid crystal panel 32B, 32G, 32R and a λ/4 retarder 31B, 31G, 31R are provided, one set disposed in the optical path between the wavelength separator 34 and th "blu " r flector 2B, on in the path between th wavelength separator and the "green" r flector 2G, and on in the path betwe n the wav length separator and the "red" r flector 2R. Each of the liquid crystal panel and λ/4 retard r combinations can be optimised for the central wavel ngth of each primary colour.

[0059] Figure 8 shows a modification of the embodiment of Figure 7, in which the three liquid crystal panels of Figure 7 are replaced by a single liquid crystal panel placed in the optical path between the polarising beam splitter and the wavelength separator 34. The three λ/4 retarders are optimised for blue, green and red light, respectively. A full colour display is provided by using a colour pixelated liquid crystal panel, or by a time-multiplex method. Preferably, the liquid crystal panel is an out-of-plane switching nematic liquid crystal panel, as this would enable the retardation of the liquid crystal panel to be optimised for the required colour.

[0060] Figure 9 shows a further embodiment of the invention, in which the liquid crystal panel and λ/4 retarder combinations of the device of Figure 6 are each replaced by a three panel system as shown in Figure 7.

[0061] In a further embodiment of the invention shown in Figure 10, the liquid crystal panel and λ/4 retarder combinations of the device of Figure 6 are each replaced by a three panel system as shown in Figure 8.

[0062] The embodiments of Figures 9 and 10 combine the advantages of the embodiment of Figure 6 with the embodiment of Figures 7 and 8. The provision of two liquid crystal panels (Figure 10) or of two sets of liquid crystal panels (Figure 9) allows a 3-D projection system to be provided, as set out above with reference to Figure 6. Alternatively, the system can be arranged to divide the grey level load between the two panels (or between the two sets of panels). If the two panels (or the two sets of panels) display the same information, then the brightness of the display is increased.

[0063] The use of separate retarders for each primary colour allows the retardation to be optimised for the central wavelength of each primary colour.

[0064] Although the wavelength separators shown in Figures 7 to 10 separate light into three components, the invention is not limited to this. It would be possible, for example, for the wavelength separator to separate visible light into two components, such as a primary colour and its complementary colour. In this case, only two reflectors and two retarder arrangements would be necessary.

[0065] The fixed λ/4 retarders can be made from any suitable optically anisotropic material, such as a liquid crystal polymer or a reactive mesogen which is cross-linked to form a polymer. Any suitable conventional liquid crystal cell, such as those described in UK patent application No 9622733.5, can be used. The liquid crystal cells, when of the nematic type, may be a Fredericks cell, a HAN cell or a Pi cell.

Claims

1. A reflective liquid crystal device comprising: a polarising beam splitter (30), a polarisation preserving reflector (2), and a retarder arrangement comprising at least two retarders (31, 32), a first (32) of which is disposed between the beam splitter (30) and the reflector (2), and a second (31) of which is disposed between the first retarder (32) and the reflector (2), at least one of the first and second retarders comprising a liquid crystal layer which is switchable between a dark device state, in which the retarder arrangement rotates the plane of polarisation of plane-polarised light directed by the beam splitter (30) towards the reflector (2) by substantially n x 180°, where n is an integer, and a bright device state; characterised in that in the bright device state the first retarder (32) has a retardation of substantially $\lambda/2$ and the second retarder (31) has a retardation of substantially $\lambda/4$.

2. A device as claimed in Claim 1 wherein the retarder arrangement rotates the plane of polarisation of plane-polarised light directed by the beam splitter towards the reflector by substantially 90° in the bright device state.

3. A device as claimed in Claim 1 or 2 wherein in the bright device state the first retarder (32) has its optic axis at an angle α to the plane of polarisation of the plane polarised light directed by the beam splitter (30) towards the reflector (2), and the second retarder (31) has its optic axis at an angle $2\alpha + 45°$ to the plane of polarisation of the plane polarised light directed by the beam splitter (30) towards the reflector (2).

4. A device as claimed in Claim 3 wherein α is substantially equal to 22.5°.

5. A device as claimed in Claim 3 wherein the first and second retarders (32, 31) each comprise a liquid crystal layer, and α is substantially equal to 15°.

6. A device as claimed in any one of Claims 1 to 4, in which the first retarder (32) comprises the liquid crystal layer whose optic axis rotates by an angle substantially equal to 22.5° about the normal direction of light passage during switching.

7. A device as claimed in any one of Claims 1 to 4, in which the first retarder (32) comprises the liquid crystal layer and has a retardation which is switchable between substantially $p\lambda/2$ and substantially $(p+1)\lambda/2$, where p is an integer.

8. A device as claimed in Claim 7, in which p is equal to zero or one.

9. A device as claimed in Claim 7 or 8, in which the liquid crystal layer is an out-of-plane switching nematic liquid crystal.

10. A device as claimed in Claim 6, in which the liquid crystal layer is a ferroelectric liquid crystal.

11. A device as claimed in Claim 6, in which the liquid crystal layer is an antiferroelectric liquid crystal.

12. A device as claimed in Claim 6, in which the liquid crystal layer is an electroclinic liquid crystal.

13. A device as claimed in Claim 6, in which the liquid crystal layer is an in-plane switching nematic liquid crystal.

14. A device as claimed in any preceding claim and further comprising a second polarisation preserving reflector (2'), and another retarder arrangement comprising a third retarder (32') disposed between the beam splitter (30) and the second reflector (2') and a fourth retarder (31') disposed between the third retarder (32') and the second reflector (2'), at least one of the third and fourth retarders comprising another liquid crystal layer which is switchable between a dark device state, in which the another retarder arrangement rotates the plane of polarisation of plane-polarised light directed by the beam splitter (30) towards the second reflector (2') by substantially n x 180°, where n is an integer, and a bright device state.

15. A reflective liquid crystal device comprising: a polarising beam splitter (30) for directing light towards a wavelength separator (34, 34'); first and second polarisation preserving reflectors (2B, 2G, 2R, 2B' 2G', 2R'), the wavelength separator (34, 34') directing light of a first wavelength towards the first reflector and directing light of a second wavelength different from the first wavelength towards the second reflector; a first retarder arrangement (31B, 32B; 31G, 32G; 31R, 32R; 31B', 32B'; 31G', 32G'; 31R'; 32R'; 32, 31B, 31G, 31R; 32', 31B', 31G', 31R') disposed in the optical path between the beam splitter and the first reflector; and a second retarder arrangement (31B, 32B; 31G, 32G; 31R, 32R; 31B', 32B'; 31G', 32G'; 31R'; 32R'; 32, 31B, 31G, 31R; 32', 31B', 31G', 31R') disposed in the optical path between the beam splitter and the second reflector;

wherein the first retarder arrangement is switchable between a dark state, in which the first retarder arrangement rotates the plane of polarisation of plane-polarised light of the first wavelength directed by the beam splitter towards the first reflector via the wavelength separator by substantially n x 180°, where n is an

integer and a bright state;
and wher in the second retarder arrangement is switchable between a dark stat , in which the second retarder arrangement rotat s the plane of polarisation of plane-polarised light of the second wavelength directed by the beam splitter towards the second reflector via the wavelength separator by substantially n x 180°, where n is an integer and a bright state;
characterised in that the first retarder arrangement comprises, in the bright state, a first retarder having a retardation of substantially λ/2 disposed between the beam splitter and the first reflector and a second retarder having a retardation of substantially λ/4 disposed between the first retarder and the first reflector;
and in that the second retarder arrangement comprises, in the bright state, a third retarder having a retardation of substantially λ/2 disposed between the beam splitter and the second reflector and a fourth retarder having a retardation of substantially λ/4 disposed between the third retarder and the second reflector.

16. A device as claimed in Claim 15, wherein the first retarder comprises a first liquid crystal layer (32, 32B, 32G, 32R);

and wherein the third retarder comprises a second liquid crystal layer (32, 32B, 32G, 32R).

17. A device as claimed in Claim 16, wherein the first liquid crystal layer (32) is the second liquid crystal layer (32).

FIG 1(a)

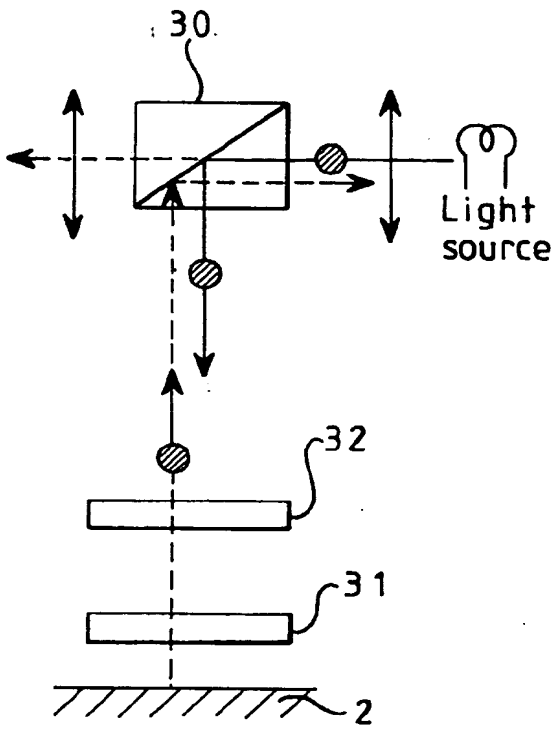
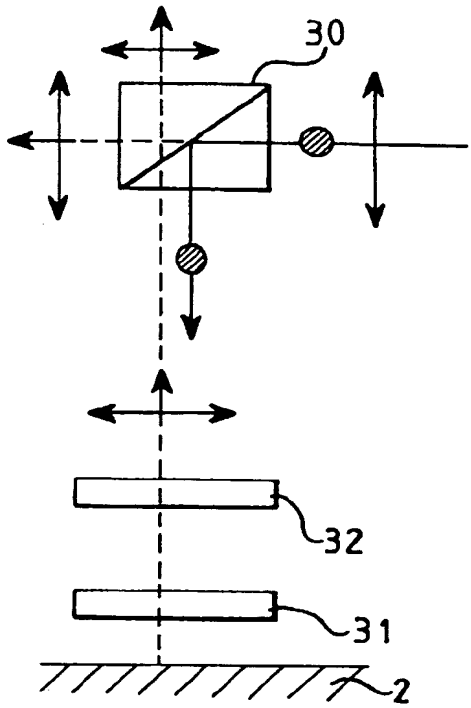


FIG 1(b)



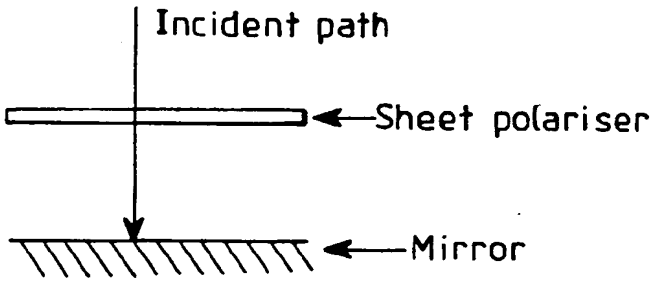
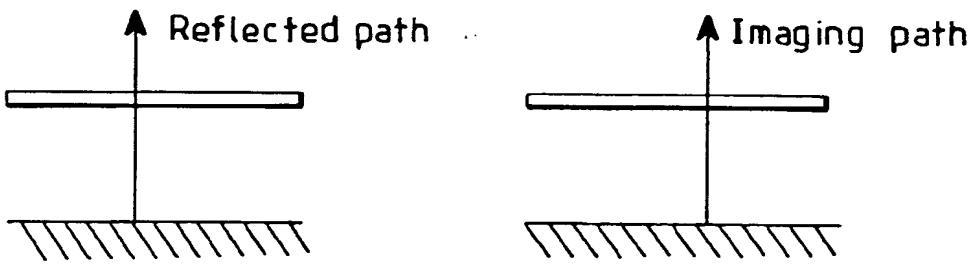


FIG 2(a)



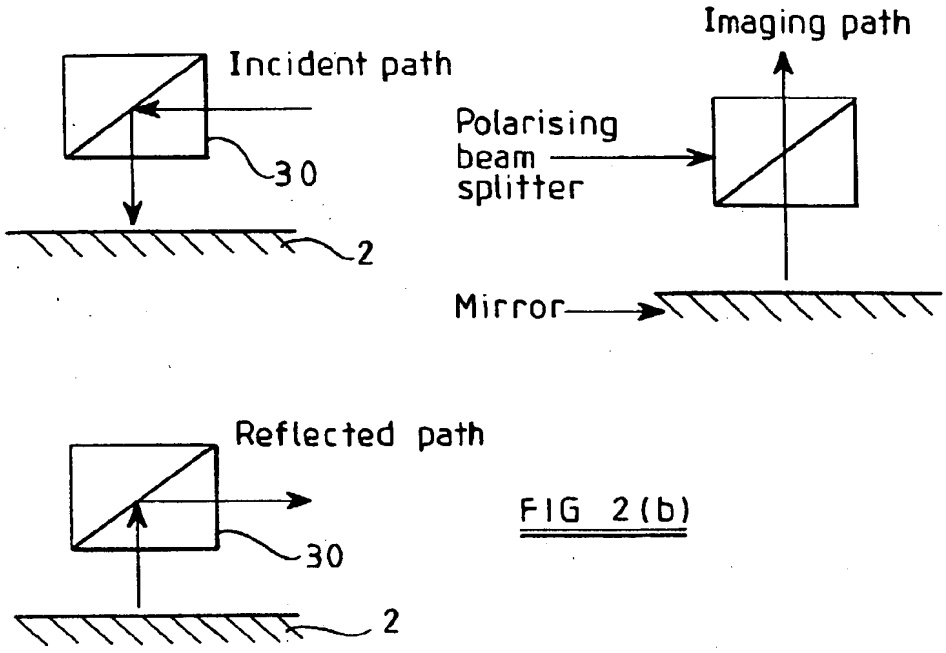

Incident path
30
2
Imaging path
Polarising
beam
splitter
Mirror
Reflected path
30
2

FIG 2(b)

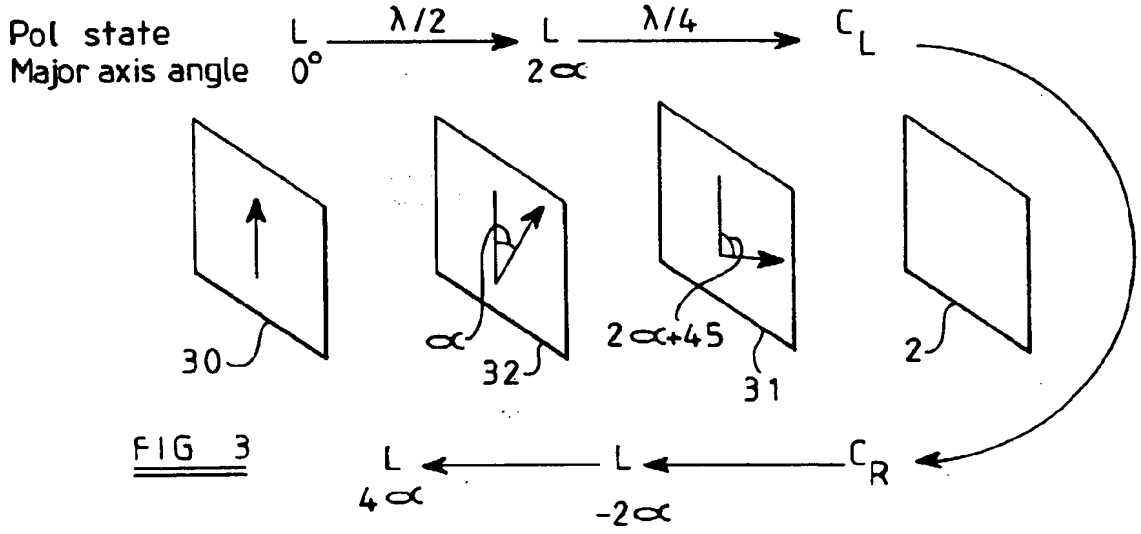

Pol state
Major axis angle
L
0°
λ/2
L
2α
λ/4
C_L
30
α
32
2α+45
31
2
L
4α
L
-2α
C_R

FIG 3

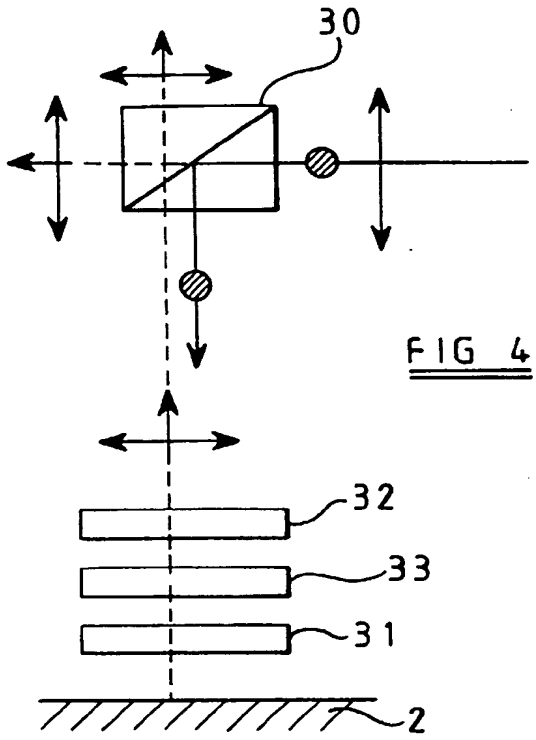


FIG 4

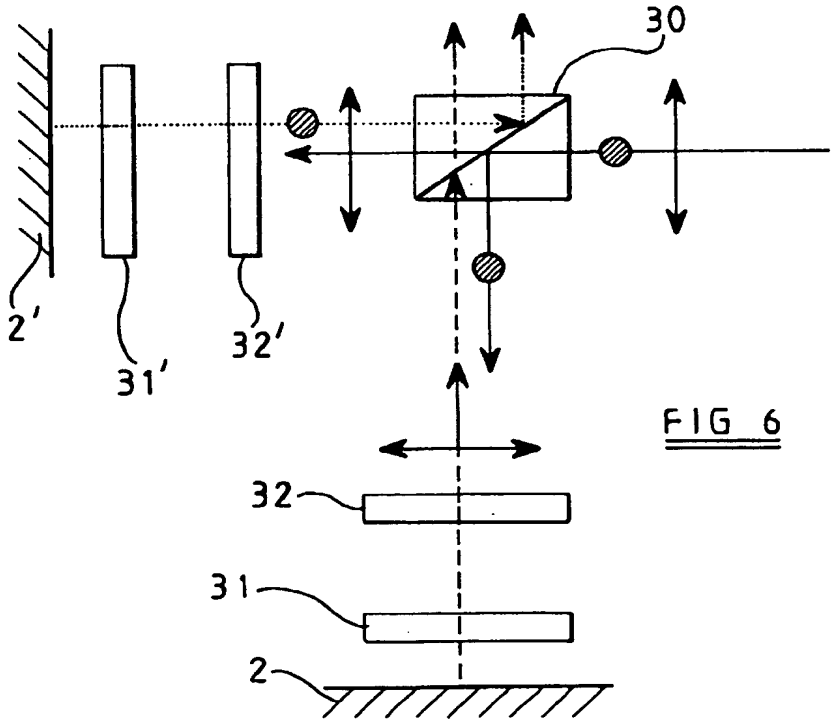
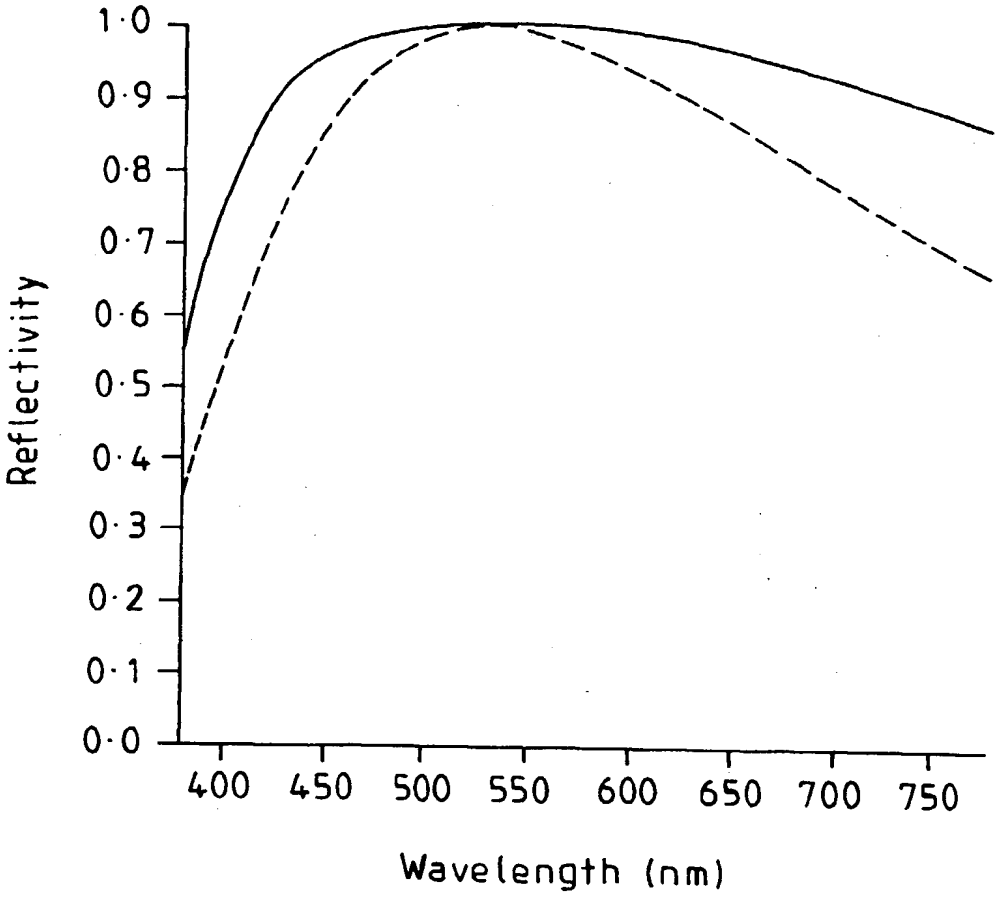


FIG 6

FIG 5


1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0·0
Reflectivity
400
450
500
550
600
650
700
750
Wavelength (nm)

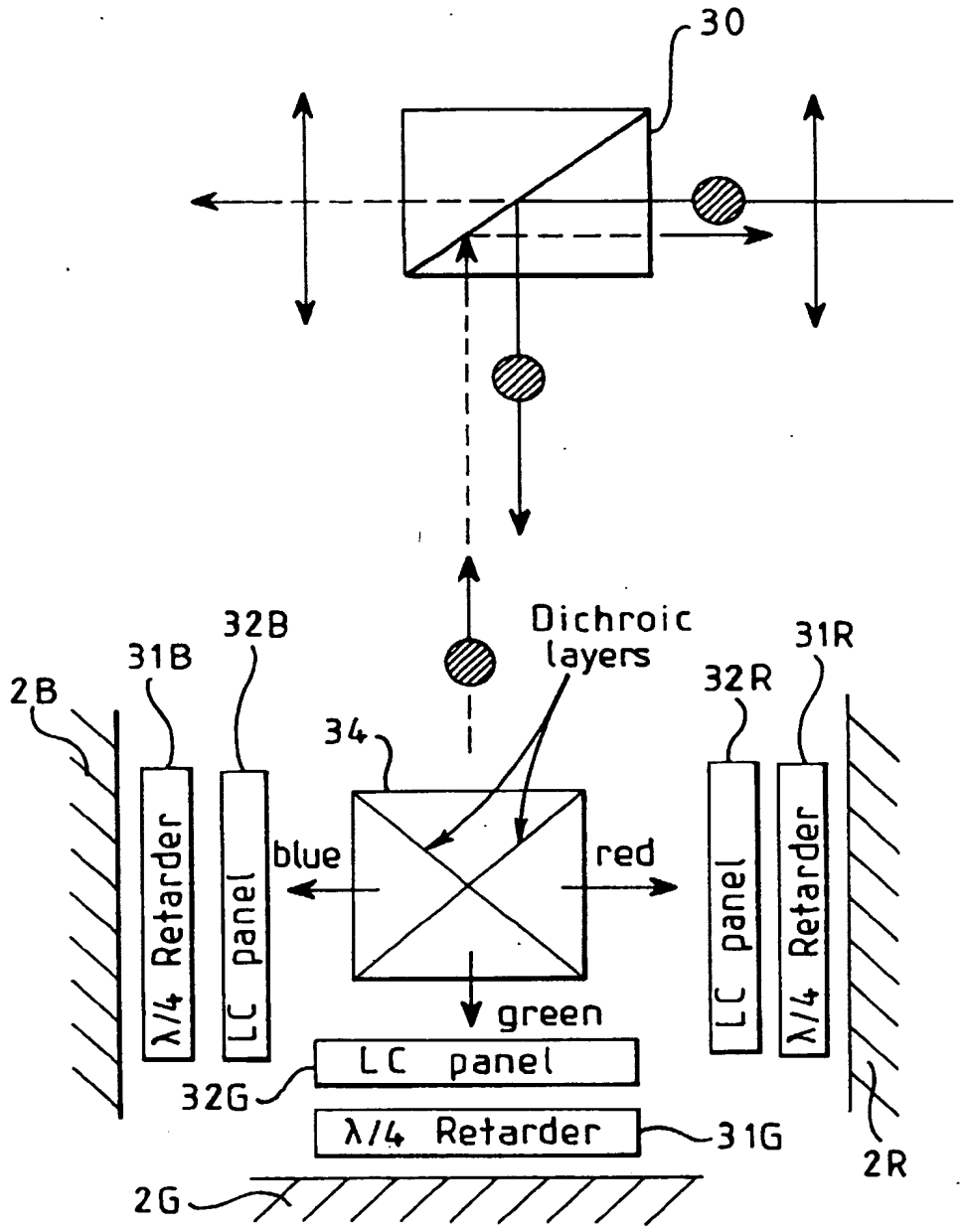

30
Dichroic layers
31B
32B
2B
34
31R
32R
blue
red
green
λ/4 Retarder
LC panel
LC panel
λ/4 Retarder
LC panel
32G
λ/4 Retarder
31G
2G
2R

FIG 7

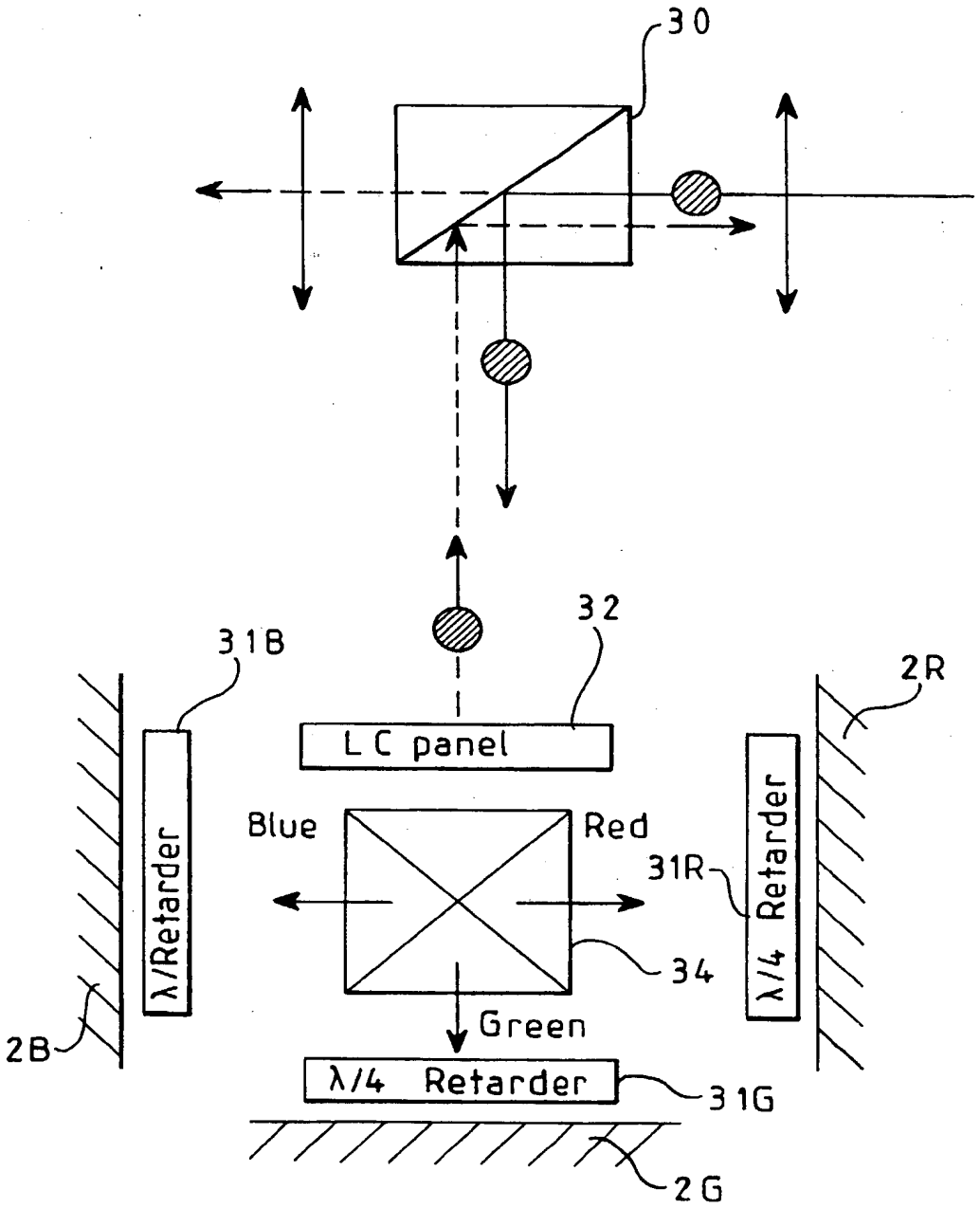

30
32
31B
2R
LC panel
λ/Retarder
λ/4 Retarder
Blue
Red
31R
34
Green
2B
λ/4 Retarder
31G
2G

FIG 8

FIG 9

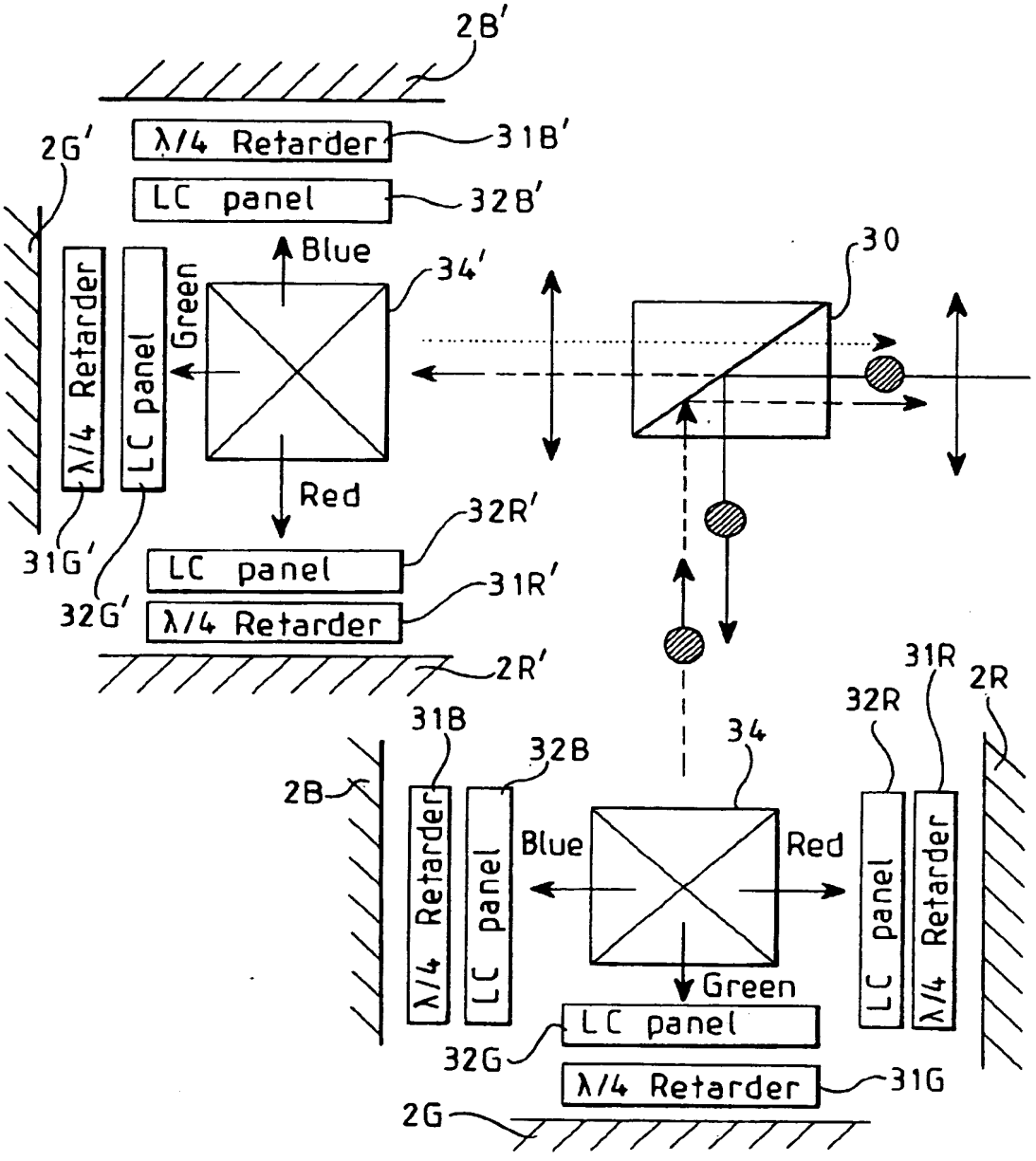
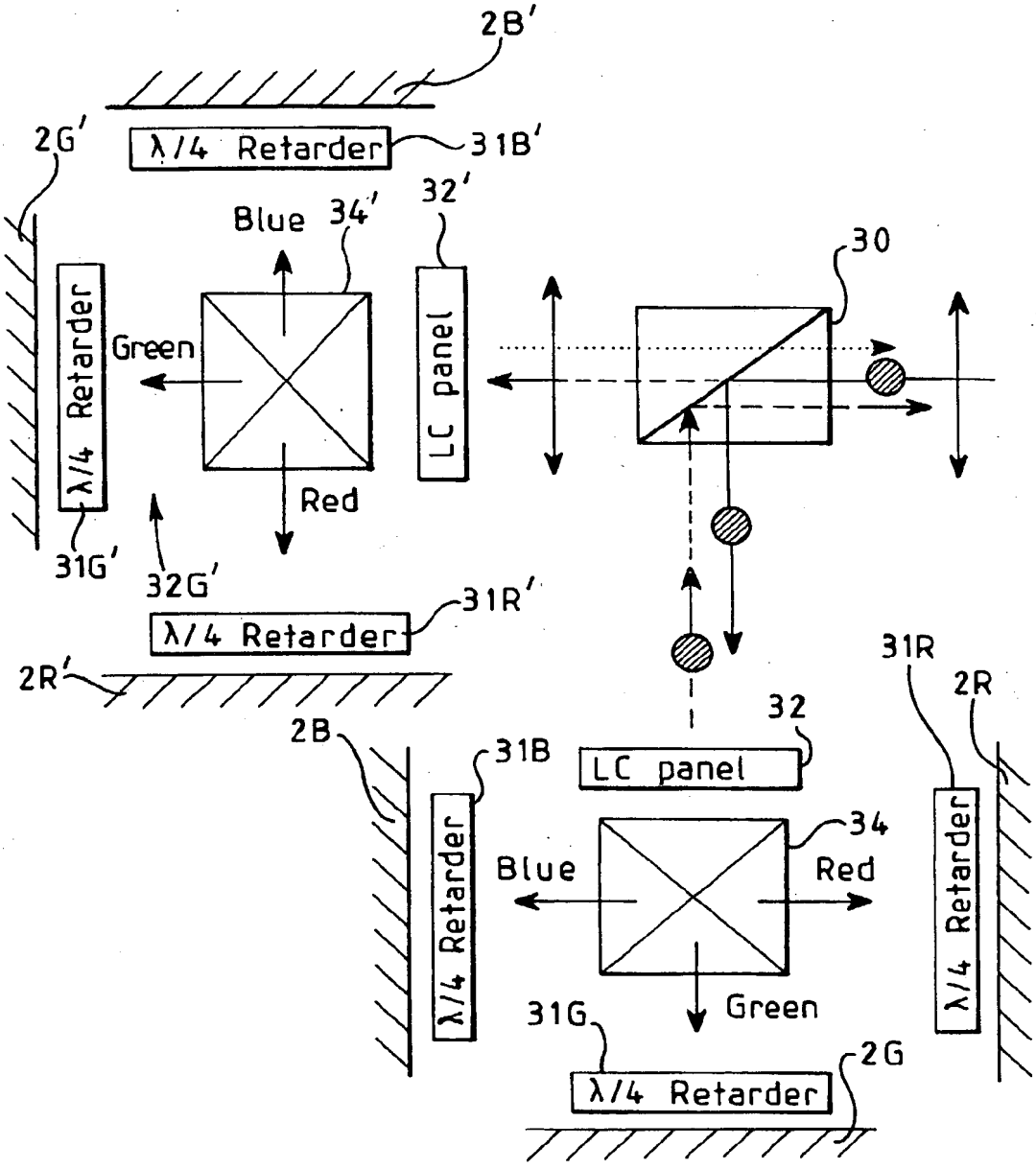

2B'
λ/4 Retarder
31B'
2G'
LC panel
32B'
Blue
34'
30
λ/4 Retarder
LC panel
Green
Red
32R'
LC panel
31G'
31R'
32G'
λ/4 Retarder
2R'
31R
2R
32R
31B
32B
34
2B
Blue
Red
λ/4 Retarder
LC panel
LC panel
λ/4 Retarder
Green
LC panel
32G
λ/4 Retarder
31G
2G

FIG 10


2B'
2G'
λ/4 Retarder
31B'
Blue
34'
32'
30
λ/4 Retarder
Green
LC panel
Red
31G'
32G'
λ/4 Retarder
31R'
2R'
31R
2R
2B
31B
32
LC panel
λ/4 Retarder
34
Blue
Red
Green
31G
2G
λ/4 Retarder
λ/4 Retarder

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European Patent Office
Office europ,en des brevets

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(54) Reflective liquid crystal device

(57) A reflective liquid crystal device comprises a polarising beam splitter 30 and a mirror 2 between which are disposed retarders 31, 32, 33. At least one of the retarders 32 is a liquid crystal element whose retardation is variable, or whose optic axis is switchable. In a DARK state of the device the retarders combine to rotate the plane of polarisation of light directed by the polarising beam splitter 30 towards a reflector 2 by n x 180ø, where n is an integer. The light returned to the polarising beam splitter is therefore directed back towards the light source. In a BRIGHT state of the device, the retarder arrangement rotates the plane of polarisation of light directed by the polarising beam splitter 30 by 90ø , and this light is transmitted by the polarising beam splitter.

FIG 1(a)

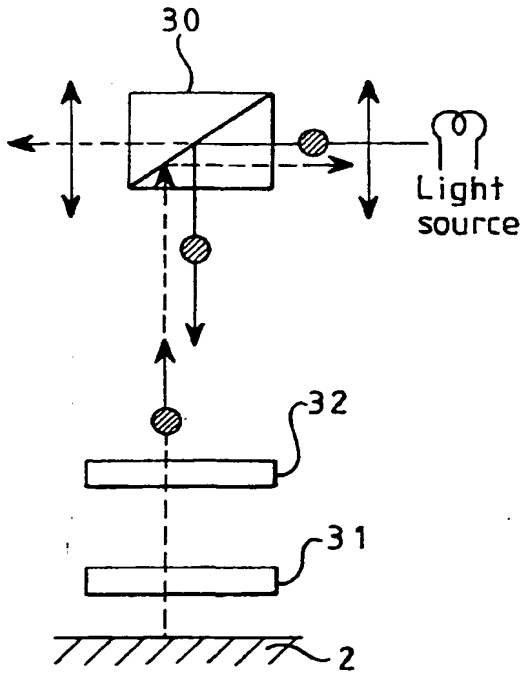

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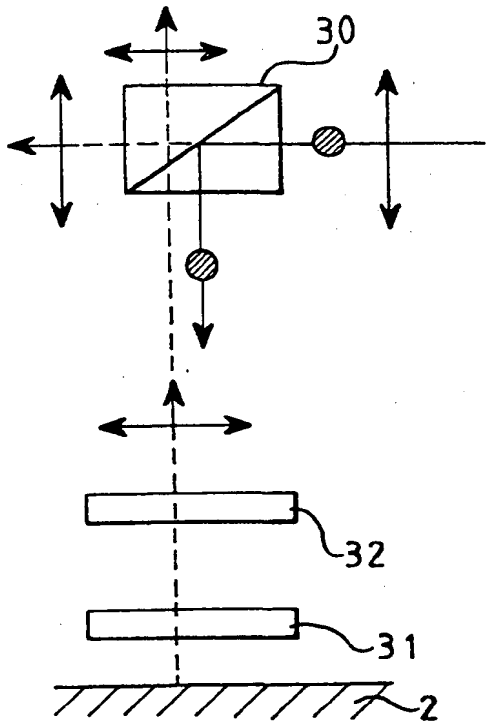
FIG 1(b)



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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 8272

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	WO 95 15513 A (ISIS INNOVATION ;PAIGE EDWARD GEORGE SYDNEY (GB); NEIL MARK ANDREW) 8 June 1995 (1995-06-08) * page 12, line 01 - page 17, line 08; figure 4 *	1,2,4, 6-8, 10-12 3,5, 14-17	G02F1/1335 G02F1/1343 G02F1/139
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Y,D	EP 0 389 240 A (MATSUSHITA ELECTRIC IND CO LTD) 26 September 1990 (1990-09-26) * column 1, line 08 - column 9, line 46; figures 3,9 *	14-17	
A	GLUECK J ET AL: "IMPROVEMENT IN LIGHT EFFICIENCY OF A-SI:H TFT-ADDRESSED REFLECTIVE /4-HAN-MODE LIGHT VALVES FOR COLOR TV PROJECTION" SID INTERNATIONAL SYMPOSIUM - DIGEST OF TECHNICAL PAPERS,US,PLAYA DEL REY, SID, vol. 24, 1993, pages 299-302, XP000470758 ISSN: 0097-966X CHAPTER: INTRODUCTION * figure 1 *	15-17	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G02F
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-/--

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28 January 2000	Diot, P

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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 8272

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
P,A	TILLIN M ET AL: "REFLECTIVE SINGLE POLARISER LOW AND HIGH TWIST LIQUID-CRYSTAL DISPLAYS" SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS,US,SANTA ANA, CA: SID, vol. 29, 1998, pages 311-314, XP002129021 ISSN: 0098-966X * the whole document *	9-13	
A,P, D	EP 0 840 160 A (SHARP KK) 6 May 1998 (1998-05-06) * column 13, line 50 - column 14, line 09; figure 13 *	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28 January 2000	Diot, P

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